

# **DELTA RISK MANAGEMENT STRATEGY**

## **INITIAL TECHNICAL FRAMEWORK PAPER**

### **WIND WAVES**

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## **Foreword**

The purpose of the Delta Risk Management Strategy (DRMS) Initial Technical Framework (ITF) is to guide the analysis of specific technical topics as they relate to assessing potential risks to Delta levees and assets resulting from various potential impacts (e.g., floods, earthquakes, subsidence, and climate change). These ITFs are considered “starting points” for the work that is to proceed on each topic. As the work is developed, improvements or modifications to the methodology presented in this ITF may occur.

Wind generated waves that persist in the Delta can lead to overtopping and erosion along levees protecting Delta islands from flooding. Levees may be weakened by the erosion, resulting in levee conditions that are more susceptible to failure and breaching during extreme storm events. In addition, during catastrophic levee breach events, fetch lengths created as a result of Delta island flooding will exacerbate erosive forces on the internal slopes of island levees.

This ITF paper outlines a methodology to approximate potential wind wave characteristics in the Delta and Suisun Bay and to assess wind wave erosive potential along levees that may develop during both seasonal weather conditions and extreme storm events. Results from these analyses will be used to provide information to and support assessments by both the Levee Fragility and the Hydrodynamics Groups.

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## **1.0 INTRODUCTION**

Wind generated waves that persist in the Delta can lead to overtopping and erosion along levees protecting Delta islands from flooding. Levees may be weakened by the erosion, resulting in levee conditions that are more susceptible to failure and breaching during extreme storm events. In addition, during catastrophic levee breach events, fetch lengths created as a result of Delta island flooding will exacerbate erosive forces on the internal slopes of island levees.

This ITF paper outlines a methodology to approximate potential wind wave characteristics in the Delta and Suisun Bay and to assess wind wave erosive potential along levees that may develop during both seasonal weather conditions and extreme storm events. Results from these analyses will be used to provide information to and support assessments by both the Levee Fragility and the Hydrodynamics Groups.

## **2.0 PURPOSE**

The purpose of the proposed work is to develop an automated tool to predict wind wave conditions and output the following results:

- Seasonal and extreme wind conditions (speeds and directions).
- Predicted wind wave heights and periods under seasonal and extreme wind conditions.
- Estimated wave runup elevations.
- Cumulative wave power estimates under seasonal and extreme wind conditions.

User-defined locations in the Delta and Suisun Bay, fetch lengths, and water depths will be required as input for the automated tool.

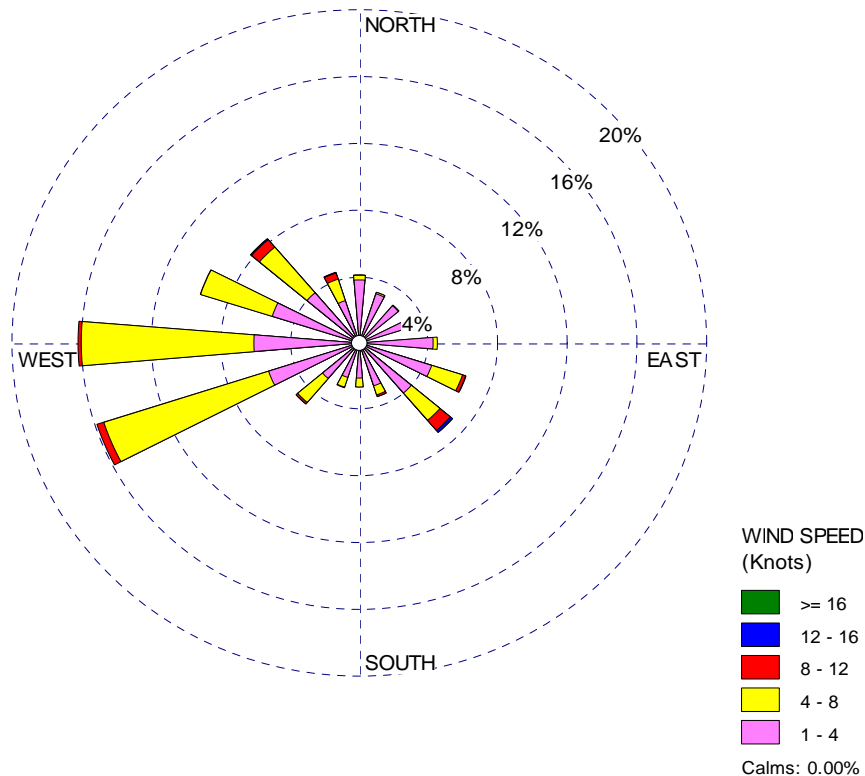
## **3.0 PHYSICAL SYSTEM AND PROBLEM**

A simplified approach to determining wind wave growth utilizes three basic inputs: (1) wind speed, (2) fetch length, and (3) water depth. Wind speeds, direction and water depths will vary in relation to seasonal conditions and extreme storm events and location in the Delta. Wind fetches are limited by the physical layout of open waterways, channels, and levees. However, during a scenario in which a levee is breached and a flooded Delta island conditions exists, the lengths of wind fetches will most likely increase and create opportunities for larger wind waves and erosive forces to develop. While the frequency of occurrence of winds can be considered statistically stationary over the long term, wave generation fetches and wave climate are likely to become more extreme over time. Relative sea level rise (including land subsidence) will increase depths and island flooding, if it occurs, will increase fetch areas.

## **4.0 ENGINEERING SCIENTIFIC METHODS**

Based on existing topography and historical wind measurements, the Delta and Suisun Bay will be divided into climate zones differentiated by seasonal and extreme wind data. With historical wind data, each zone will be assigned a seasonal wind climate in graphical format such as a wind rose. As shown in Figure 1, a wind rose is a diagram that depicts the distribution of wind speed and direction over the period of observation.

Extreme high wind speeds will also be analyzed in order to assign wind speeds for rare events (say return periods of 2, 5, 10, 25, 50, and 100 years). Wind speed-duration relationships from the Coastal Engineering Manual (CEM) (USACE 2003) will be used to convert both seasonal and extreme wind speeds into appropriate values for use in the simplified wind wave growth equations.



**Figure 1: Wind Rose**

Methods to predict wave height and wave period will be a result of simplified equations for wind wave growth from the CEM (USACE 2003). The CEM reports that these methods are desirable to estimate wave conditions for preliminary considerations in project design or for final design when project costs are minimal (USACE 2003). In additions to calculating wave height and wave period, the CEM methods also include a correction for wind speed sensor elevations, an estimate of duration for fetch-limited conditions, and upper bounds for both wave heights and wave periods. Water depth is a key factor in determining limiting values for both wave height and wave period. Wave height and wave period calculations, as shown in Tables 1 and 2, will be imbedded within the automated tool for each climate zone. Figures 2 and 3 show the same results for wave height and wave period, but in a graphical format.

For each generated combination of wave height and wave period, wave power will be computed as defined by linear wave theory in the CEM. Calculated values for wave power that correspond to specific wind directions will be converted to wave power values perpendicular to levee sites throughout Suisun Bay and the Delta. Cumulative wave power estimates for seasonal wind data will be made by weighting each wave power calculation by percent occurrence values for wind speed and direction that produce each

wave height and wave period combination. Cumulative wave power estimates for storm events will be based on extreme wind speeds and maximum fetch lengths.

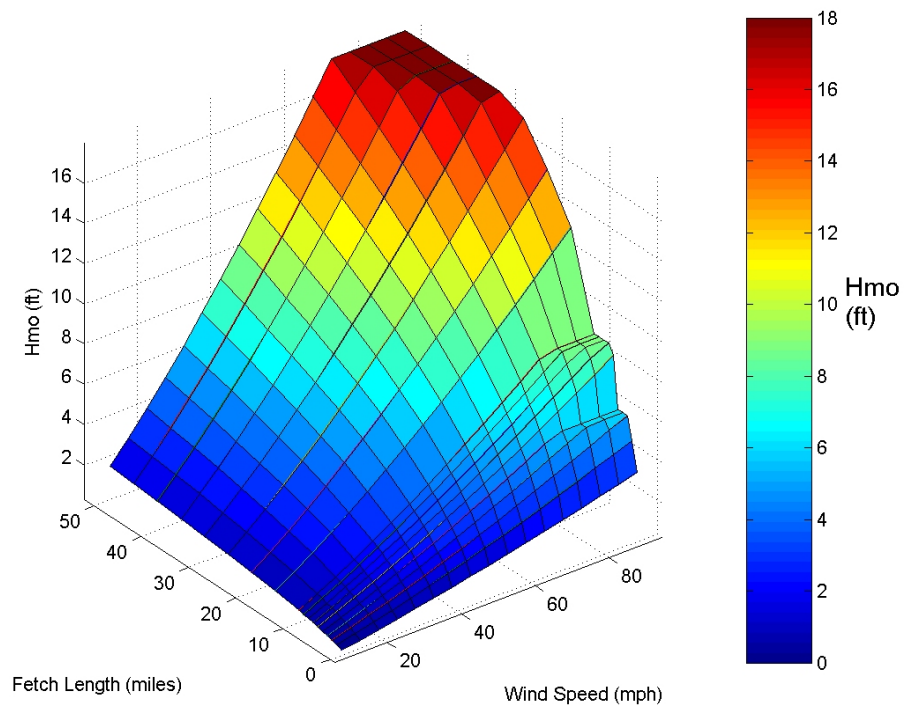
Cumulative wave power estimates can be used to assess levee erosion. While erosion depends on many parameters, the dissipation of wave energy over time is considered a primary contributor. Correlation between observed erosion and wave exposure has been used to estimate long-term cumulative effects for purposes of levee design (USACE 1998). Available data can be used to establish a relative erosion potential based on cumulative wave power. Other parameters, such as levee geometry, geotechnical information and degree of armoring should also be considered to the extent appropriate. Based on an analysis of wind waves and water levels, Figure 4 shows a plot of erosion potential at different elevations for four different levee segments at the McCormack-Williamson Tract (PWA 2005).

**Table 1**  
**Wave Height Look-Up Table**

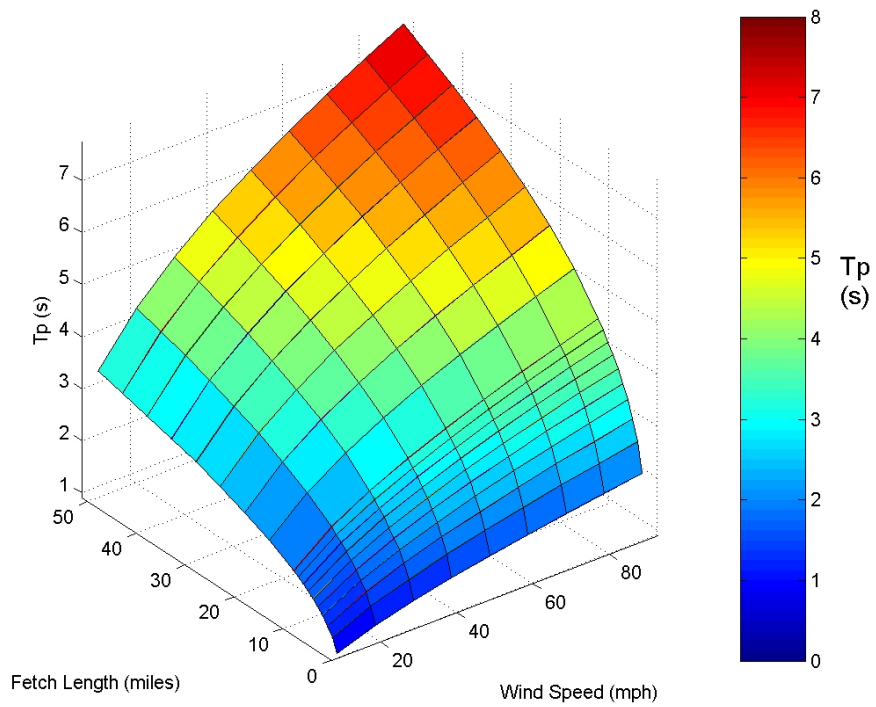
		Wave Height, $H_{mo}$ (ft)																	
		Fetch Length (miles)																	
		1	2	3	4	5	6	7	8	9	10	15	20	25	30	35	40	45	50
Wind Speed (mph)	10	0.3	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.1	1.2	1.4	1.5	1.6	1.7	1.8	1.9
	20	0.6	0.8	1.0	1.2	1.3	1.4	1.5	1.6	1.8	1.8	2.3	2.6	2.9	3.2	3.5	3.7	3.9	4.1
	30	0.9	1.3	1.6	1.8	2.1	2.3	2.4	2.6	2.8	2.9	3.6	4.1	4.6	5.1	5.5	5.8	6.2	6.5
	40	1.3	1.8	2.2	2.6	2.9	3.2	3.4	3.6	3.9	4.1	5.0	5.8	6.4	7.1	7.6	8.2	8.6	9.1
	50	1.7	2.4	2.9	3.4	3.8	4.1	4.5	4.8	5.0	5.3	6.5	7.5	8.4	9.2	10.0	10.6	11.3	11.9
	60	2.1	3.0	3.6	4.2	4.7	5.1	5.6	5.9	6.3	6.6	8.1	9.4	10.5	11.5	12.4	13.3	14.1	14.9
	70	2.5	3.6	4.4	5.1	5.7	6.2	6.7	7.2	7.6	8.0	9.9	11.4	12.7	13.9	15.1	16.1	17.1	18.0
	80	3.0	4.3	5.2	6.0	6.0	7.4	8.0	8.5	9.0	9.0	11.7	13.5	15.1	16.5	17.8	18.0	18.0	18.0
	90	3.5	4.9	6.0	6.0	6.0	8.6	9.0	9.0	9.0	9.0	13.5	15.6	17.5	18.0	18.0	18.0	18.0	18.0

**Table 2**  
**Wave Period Look-Up Table**

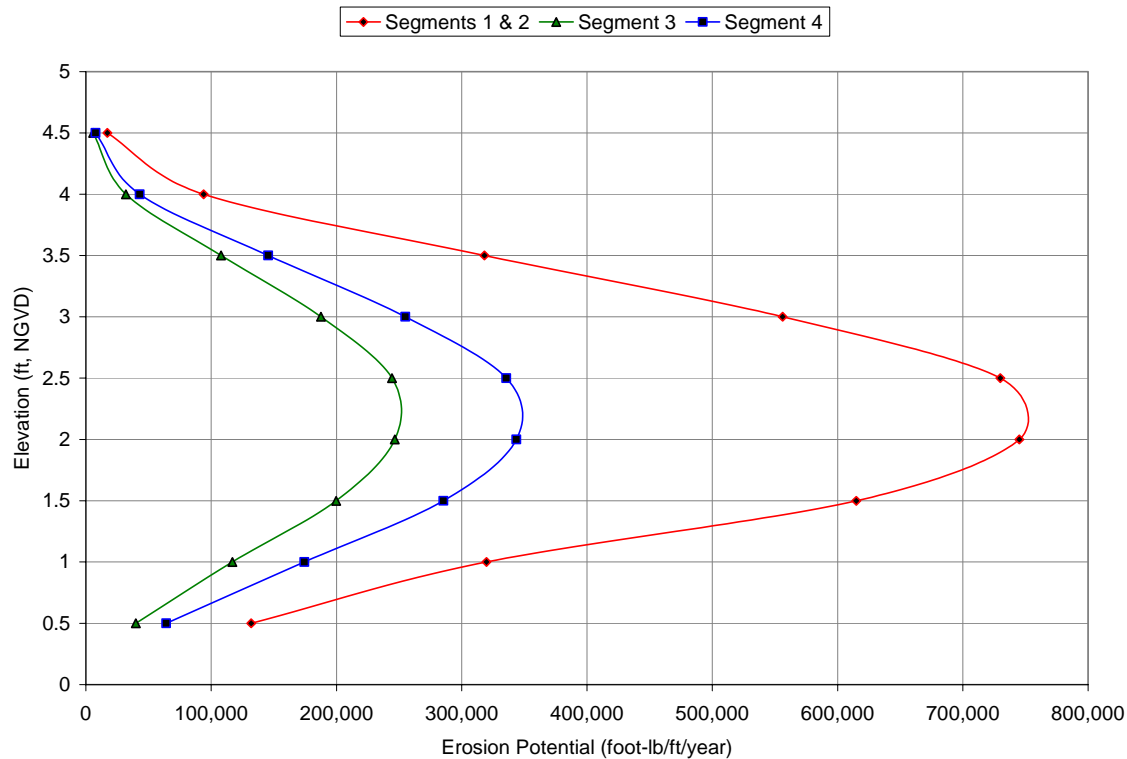
		Wave Period, $T_p$ (sec)																	
		Fetch Length (miles)																	
		1	2	3	4	5	6	7	8	9	10	15	20	25	30	35	40	45	50
Wind Speed (mph)	10	0.9	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9	2.2	2.4	2.6	2.8	2.9	3.1	3.2	3.3
	20	1.2	1.5	1.7	1.8	2.0	2.1	2.2	2.3	2.4	2.5	2.9	3.1	3.4	3.6	3.8	4.0	4.1	4.3
	30	1.3	1.7	1.9	2.1	2.3	2.5	2.6	2.7	2.8	2.9	3.3	3.7	3.9	4.2	4.4	4.6	4.8	5.0
	40	1.5	1.9	2.2	2.4	2.6	2.7	2.9	3.0	3.1	3.2	3.7	4.1	4.4	4.7	4.9	5.2	5.4	5.6
	50	1.6	2.1	2.4	2.6	2.8	3.0	3.2	3.3	3.4	3.6	4.1	4.5	4.8	5.1	5.4	5.6	5.9	6.1
	60	1.8	2.2	2.6	2.8	3.0	3.2	3.4	3.5	3.7	3.8	4.4	4.8	5.2	5.5	5.8	6.1	6.3	6.5
	70	1.9	2.4	2.7	3.0	3.2	3.4	3.6	3.8	3.9	4.1	4.7	5.1	5.5	5.9	6.2	6.5	6.7	7.0
	80	2.0	2.5	2.9	3.2	3.4	3.6	3.8	4.0	4.2	4.3	4.9	5.4	5.8	6.2	6.5	6.8	7.1	7.4
	90	2.1	2.6	3.0	3.3	3.6	3.8	4.0	4.2	4.4	4.5	5.2	5.7	6.1	6.5	6.9	7.2	7.5	7.7



**Figure 2: Wave Height Graphical Plot**



**Figure 3: Wave Period Graphical Plot**



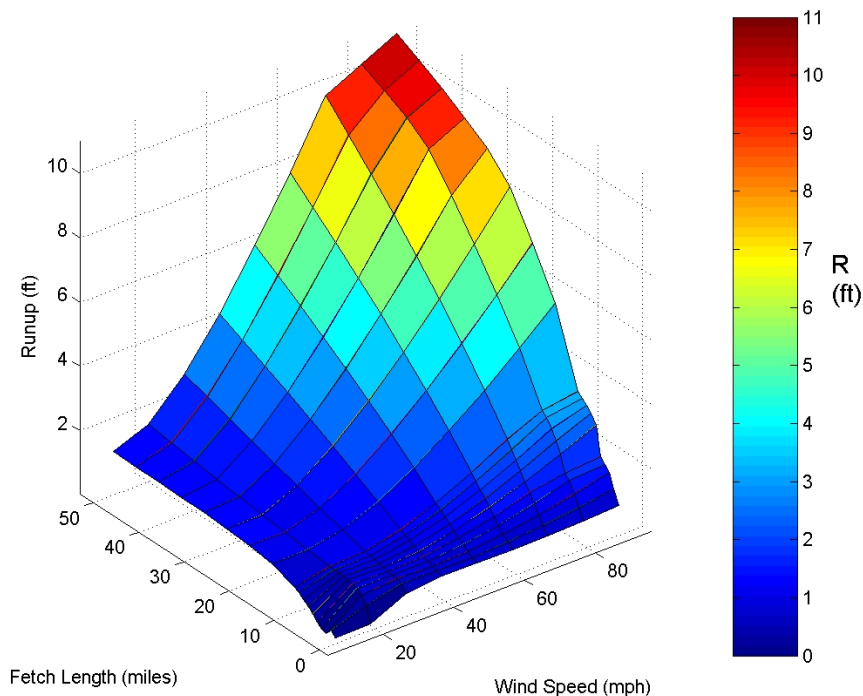
**Figure 4: Erosion Potential for Annual Conditions at McCormack-Williamson Tract (PWA 2005)**

Estimates of wave runup depend on wind wave characteristics, levee geometry, and levee bank conditions. Wave runup elevations represent the expected elevation that the swash from a breaking wave will reach up the levee slope assuming an infinite extension of the bank slope. The wave runup method proposed for this work is from van der Meer (2002) and intended to be useful for coastal and estuarine waters with shallow or very shallow foreshores in front of hard barriers such as a flood protection levee. The wave runup method from van der Meer (2002) takes into account reduction factors for surface roughness, the influence of a berm, and angled wave approach. This wave runup method from van der Meer (2002) has been documented in the FEMA final draft guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast (FEMA 2005). Similar to wave height and wave period calculations, wave runup estimates will also be imbedded within the automated tool. Table 3 shows a table of wave runup estimates for a smooth levee side slope of 10 horizontal to 1 vertical (H:V) and Figure 5 shows the estimates in a graphical format.



**Table 3**  
**Wave Runup Look-Up Table**

		Wave Runup, $R_{2\%}$ (ft)																	
		Fetch Length (miles)																	
Wind Speed (mph)		1	2	3	4	5	6	7	8	9	10	15	20	25	30	35	40	45	50
	10	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	1.0	1.1	1.3	1.4	1.5	1.6	1.7
	20	0.3	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.2	1.6	1.8	2.1	2.3	2.6	2.8	3.0	3.2
	30	0.5	0.7	0.9	1.1	1.2	1.3	1.5	1.6	1.7	1.8	2.3	2.7	3.1	3.4	3.8	4.1	4.3	4.6
	40	0.6	0.9	1.2	1.4	1.6	1.8	1.9	2.1	2.2	2.4	3.0	3.6	4.1	4.5	5.0	5.4	5.7	6.1
	50	0.8	1.2	1.5	1.7	2.0	2.2	2.4	2.6	2.8	3.0	3.8	4.5	5.1	5.7	6.2	6.7	7.2	7.6
	60	0.9	1.4	1.8	2.1	2.4	2.7	2.9	3.2	3.4	3.6	4.5	5.4	6.1	6.8	7.5	8.1	8.6	9.2
	70	1.1	1.6	2.1	2.5	2.8	3.1	3.4	3.7	4.0	4.2	5.3	6.3	7.2	8.0	8.7	9.5	10.1	10.8
	80	1.3	1.9	2.4	2.8	3.1	3.6	3.9	4.3	4.5	4.7	6.1	7.3	8.3	9.2	10.1	10.6	11.0	11.4
	90	1.4	2.1	2.7	3.0	3.2	4.1	4.4	4.6	4.8	4.9	7.0	8.2	9.4	10.1	10.6	11.1	11.6	12.0



**Figure 5: Wave Runup Graphical Plot**

## 5.0 PROBABILISTIC APPROACH

Although analysis of wind wave conditions and water level data in the Delta and Suisun Bay are planning to be evaluated by separate DRMS groups, it is important to note that these two physical changes can act in combination. Extreme occurrences of one process often coincide with extreme occurrences of the other. For example, during large storm events, large waves and flood water levels can often occur together. Therefore, in determining the probabilistic nature of wind speeds and predicted wave conditions, it will be important to coordinate wind event definition with the water level analysis so that wave conditions for extreme events can be superimposed onto elevated water levels.

Probability distribution functions such as the Fisher-Tippett I, Gumbel or Weibull distributions will be used to characterize extreme wind data in each zone. Data used for

this extreme analysis will only be taken from significant storm events that have been recorded in the Delta and Suisun Bay. Based on available wind data, probability distribution functions will be based on extreme wind data sets for each zone in the Delta and Suisun Bay. Confidence interval bounds will be determined for each extreme return period wind estimate for each defined zone and uncertainty associated with the correct probability distribution of the data.

The joint occurrence probability of high water levels and high wind speeds is important in the assessment of wave climate and levee erosion. Historic events that include coincident water level and wind data will be used to approximate the joint occurrence probability. Coincident data series of around 30 years can allow reasonable estimates of joint probability events with return periods on the order of 100 years (PWA 2002) and (PWA 2004). The analysis will include consideration of the duration of wind events relative to high water levels. To achieve this, historic daily data for water surface elevations will be plotted against measured wind data to analyze the correlation between these two parameters. In addition, the potential for a series of storms to result in progressive damage can also be addressed in this review of data time series. This is particularly important to assess the risk of storm occurrence after a levee has failed due to a prior wind wave event.

## **6.0 ASSUMPTIONS**

It is assumed that the availability of wind data is adequate to characterize both seasonal and extreme conditions. To determine seasonal wind conditions, it is assumed that hourly or daily measurements will be available to create representative wind roses for each zone in the Delta and Suisun Bay. To develop extreme wind data sets, it is assumed that historical records include an adequate number of significant events for each climate zone.

It is also assumed that the standard wave analysis tools identified here provide sufficient accuracy for the risk assessment. To the extent that either measured wave data are readily available or the opportunity to collect wave data exists, wind wave predictions from the automated tool can be compared to actual measurements. Any available data will allow an order-of-magnitude estimate of wave climate and extreme events.

## **7.0 INFORMATION REQUIREMENTS**

For development of the automated tool, wind data is required that includes both direction and speed. The wind data collection method is used to establish the speed-duration relationship. The frequency of occurrence of different wind speed and directions is required for the climate analysis and a list of extreme high wind speeds over a defined time period is desired for the return period analysis. These data are typically available from government agencies for most regions. Possible sources of wind data include: (1) the National Weather Service, (2) Wind in California (DWR 1978), (3) California Irrigation Management Information System (CIMIS), (4) local airports, (5) local radio and television towers with meteorological stations, and (6) other sources.

## **8.0 ANTICIPATED OUTPUT**

The automated tool will return several different types of output for each specified climate zone. The user of the automated tool will need to enter location of interest (climate zone), fetch length(s), levee geometry, levee surface conditions, and levee armoring (if any).

The automated tool will return calculations for wave height, wave period, wave runup and cumulative wave power. If the user does not enter any site specific levee data, the automated tool will return wave runup estimates that depict a number of different scenarios for typical levee geometries and side slope conditions in the Delta and Suisun Bay. The automated tool will also output wind statistics in relation to speed and direction, extreme wind estimates, and joint probability percentages for events that include both high water levels and high wind speeds.

In addition to the automated tool, a GIS map showing varying degrees of wave exposure and erosion potential will also be made for each climate zone in the Delta and Suisun Bay. This GIS map will classify each zone in terms of wave exposure by examining predominate wind speeds and directions as well as lengths of individual fetch lengths. Estimates of erosion potential will be based on cumulative wave power calculations, and both seasonal and extreme statistics for wind speeds and water levels.

## **9.0 SOFTWARE**

Required software for using the automated tool includes MATLAB and Microsoft Excel. The user will be able to set up input files and view the output look-up tables with Excel. The output will also be organized into a GIS software environment (ArcView) in order to show wave exposure and cumulative wave power results.

## **10.0 PROJECT TASKS**

Anticipated project tasks include the following:

1. Kickoff Meeting
2. Site Reconnaissance
3. Wind Data Collection
4. Zone Classification
5. Development of Wind Wave Automated Tool
6. Coordination
7. User's Manual

## **11.0 REFERENCES**

DWR (California Department of Water Resources). 1978. Wind in California, Bulletin No. 185.

FEMA (Federal Emergency Management Agency). 2005. Final Draft Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States. Prepared for the U.S. Department of Homeland Security. A Joint Project by FEMA Region IX, FEMA Region X, FEMA Headquarters.

PWA (Philip Williams & Associates). 2002. Coastal Hydraulics Phase Report for a Coastal Flood Insurance Study, Sandy Point Whatcom County Washington. Prepared for Whatcom County Public Works.

PWA. 2004. Technical Report on Wave Transformations & Storm Wave Characteristics. Report prepared for Northwest Hydraulics Consultants and FEMA.

- PWA. 2005. McCormack-Williamson Tract, Habitat Friendly Levee Design. Technical memorandum prepared for MBK Engineers.
- USACE (U.S. Army Corps of Engineers). 1998. Hamilton Army Airfield Restoration Feasibility Study. U.S. Army Corps of Engineers, San Francisco District.
- USACE. 2003. Coastal Engineering Manual. Washington D.C. Part II, Chapter 2.
- Van der Meer, J.W. 2002. Wave Run-up and Overtopping at Dikes. Technical Report, Technical Advisory Committee for Water Retaining Structures (TAW), Delft, The Netherlands.